New Global Estimates Of Cloud Ice And Liquid Water Path From MODIS Using A Profiling Method

W. Smith, P. Minnis
NASA LaRC, Hampton, VA

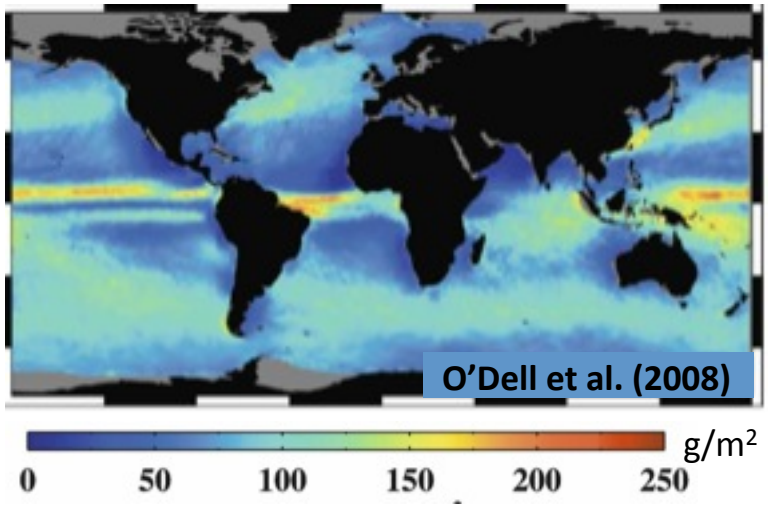
C. Fleeger, M. Khaiyer-Thieman, D. Spangenberg,
S. Sun-Mack, R. Smith, Y. Chen
R. Palikonda
SSAI, Inc. Hampton, VA

CERES Science Team Meeting, Hampton, VA, 5-7 May 2014

The global distribution of CWP is not well known

- CMIP5 models show large differences (factor of 2-10) in LWP and IWP
- No global consensus from satellite observations (different sensors have different sensitivities, attenuation limits, retrieval errors)

Microwave LWP (April 1988-2005)



Some generalizations w.r.t. observations:

Cloud Ice

- CloudSat+CALIPSO useful for IWC/IWP in upper troposphere
- Passive VIS/NIR/IR IWP useful for some SL cirrus but highly uncertain in overlapping conditions (retrieval assumes SL, vertically homogeneous clouds: all ice, $R_e(z)$=const)

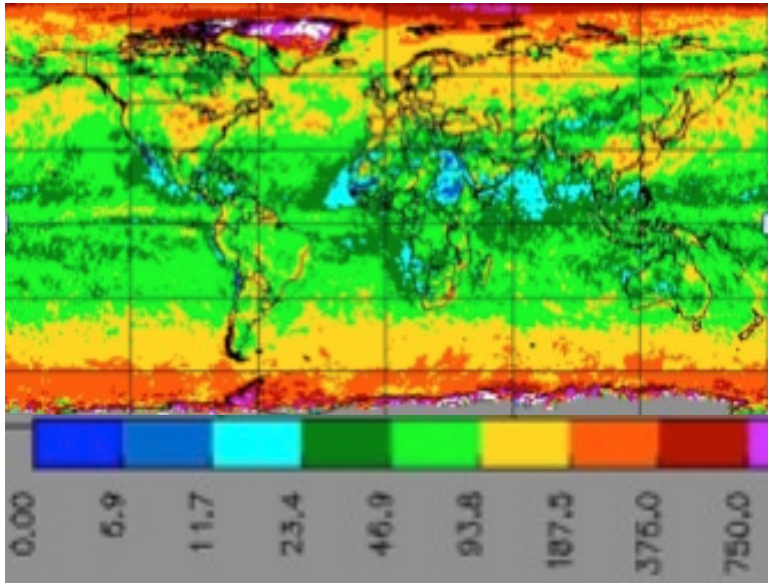
Cloud Liquid

- CloudSat useful for non-precip. B.L clouds above 1km
- Passive microwave demonstrated over oceans
- Passive VIS/NIR imager retrievals useful if unobscured (otherwise unsampled)

Mixed Phase (incl. deep ice over water clouds)

- Highly uncertain – Not accounted for in passive (VNIR). Models and CloudSat retrievals employ a variety of temperature dependent assumptions leading to large differences

CERES Ed4 MODIS LWP (April 2013)



Motivation

- Despite uncertainties, satellite cloud retrievals are becoming more valuable in weather and climate applications
- Widely used for climate model evaluation
- LaRC GEO cloud properties being assimilation into short-term forecast models
  - CTH assimilated into operational NOAA Rapid Refresh
  - IWP/LWP being assimilated experimentally in WRF at NCAR and NSSL
    - Focused on convection
    - Positive impact demonstrated despite retrieval errors (model errors much larger)
  - LWP correlated with aircraft icing potential and used in aviation safety applications (need estimates in overlapping condition e.g. winter storms)

Optically thick clouds matter. Need more accurate estimates of WP in overlapping conditions

Objectives

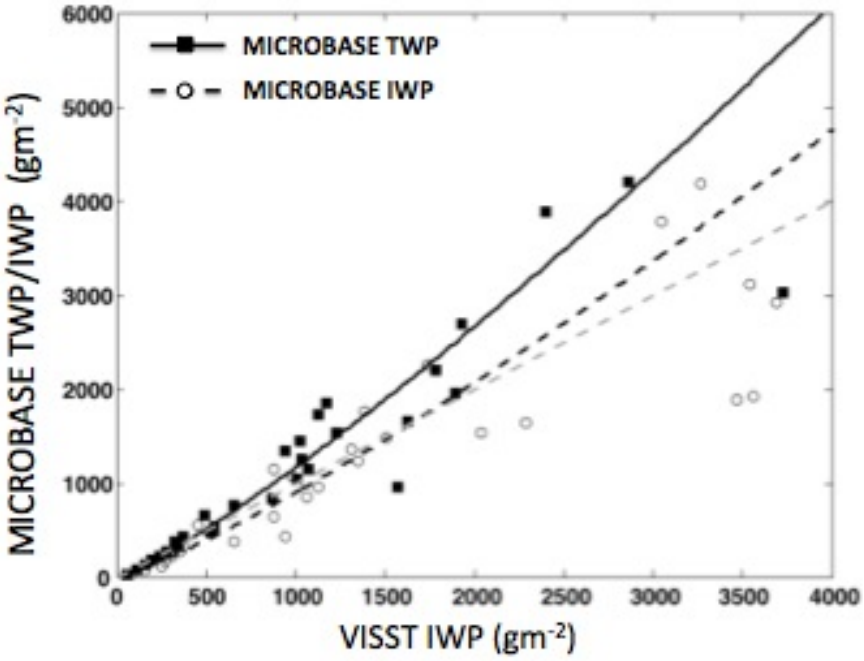
- Describe an empirical method that can be applied to VISST cloud retrievals (COD, Re) to estimate ice and liquid water content profiles in any cloud type
  - Provides new estimate of IWP **and** LWP in SL overlapping conditions (focus of this talk)
- Recent validation with CloudSat/CALIPSO, MWR and aircraft data
- Global application to CERES MODIS cloud retrievals and comparisons to standard VISST retrievals

Algorithm Description

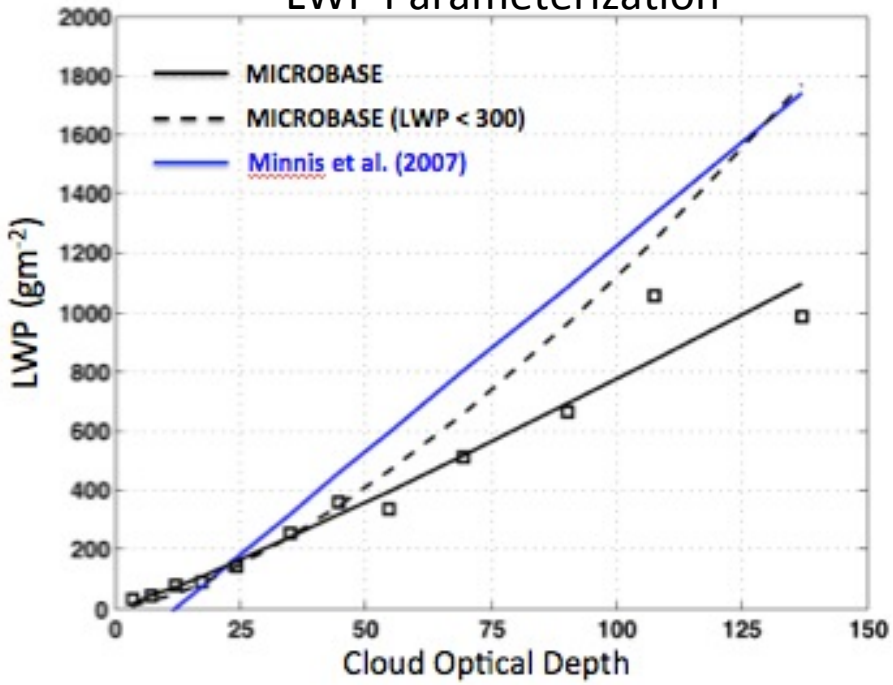
- Method is applied to daytime cloud retrievals (VISST)
- Requires knowledge of TWP
  - Assume TWP=IWP for optically thin ice clouds (tau<10) and TWP=LWP for liquid topped clouds
  - Parameterization developed for optically thick ice over water clouds (VISST IWP ≠ TWP in most ice over water clouds)
- Using climatological information on cloud vertical structure from CloudSat and NWP for lots of cloud types, derive TWC (z) constrained with TWP and VISST cloud boundaries
- In overlapping clouds, use guidance from NWP cloud model on phase partitioning and SLW observations from pilots (icing reports) to derive IWC(z) and LWC(z) from TWC(z)

Parameterization for Total Water Path (TWP)

IWP Parameterization

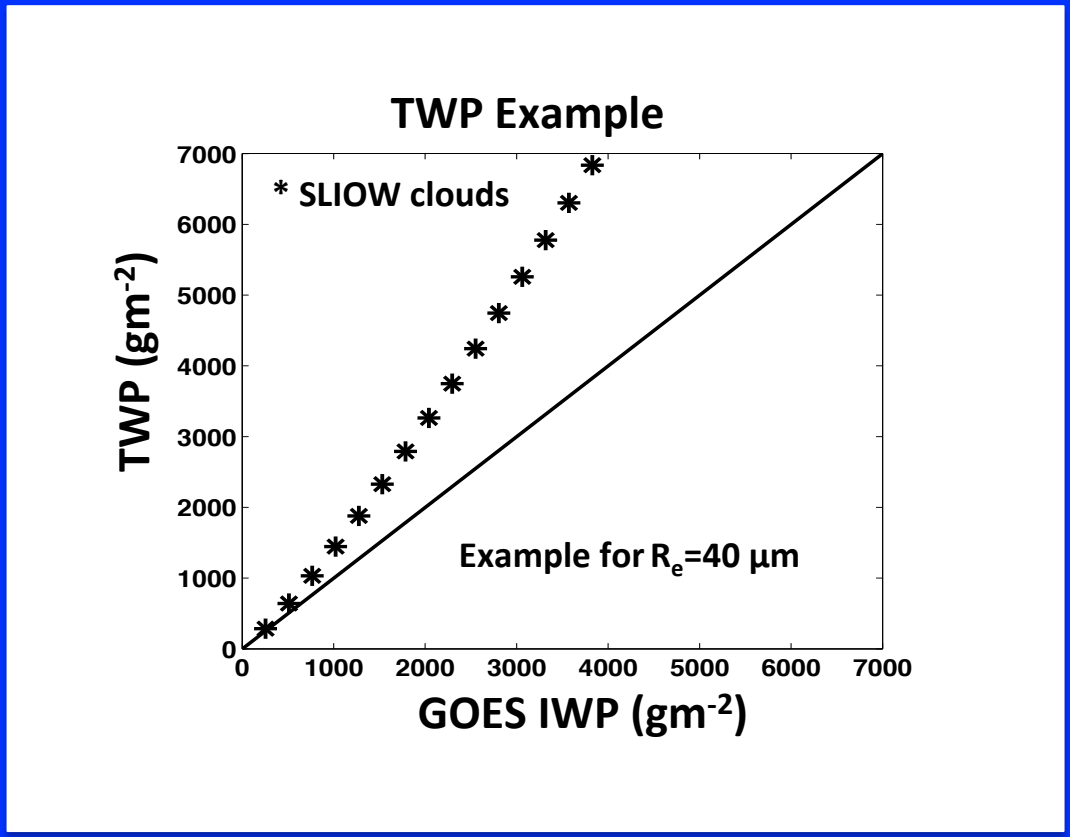


LWP Parameterization



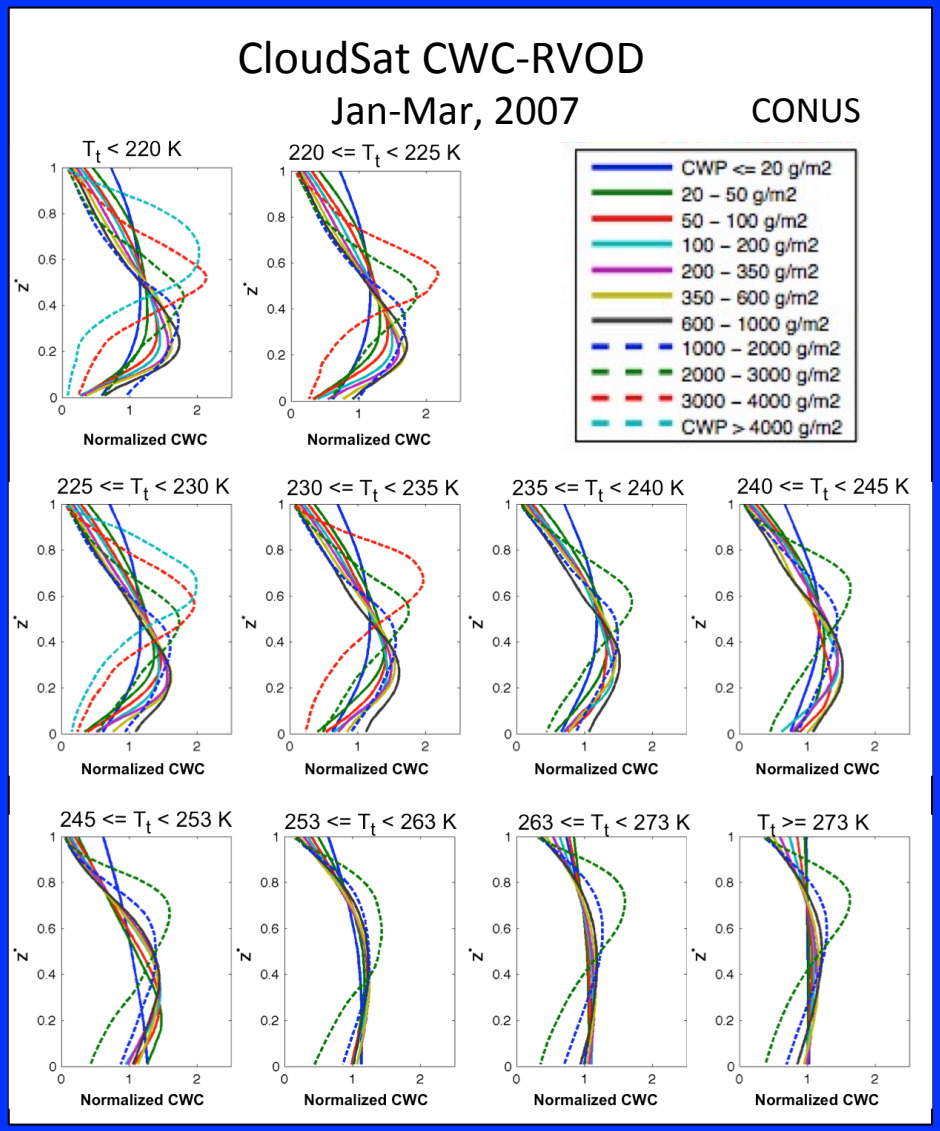
- Parameterization developed from ARM MICROBASE data (5-years, SGP site)
- Based on correlations between GOES Cloud properties and MICROBASE IWP (from MMCR) and LWP (from MWR).
- Some tuning needed to get the right answer (TWP = microbase TWP + LWP)

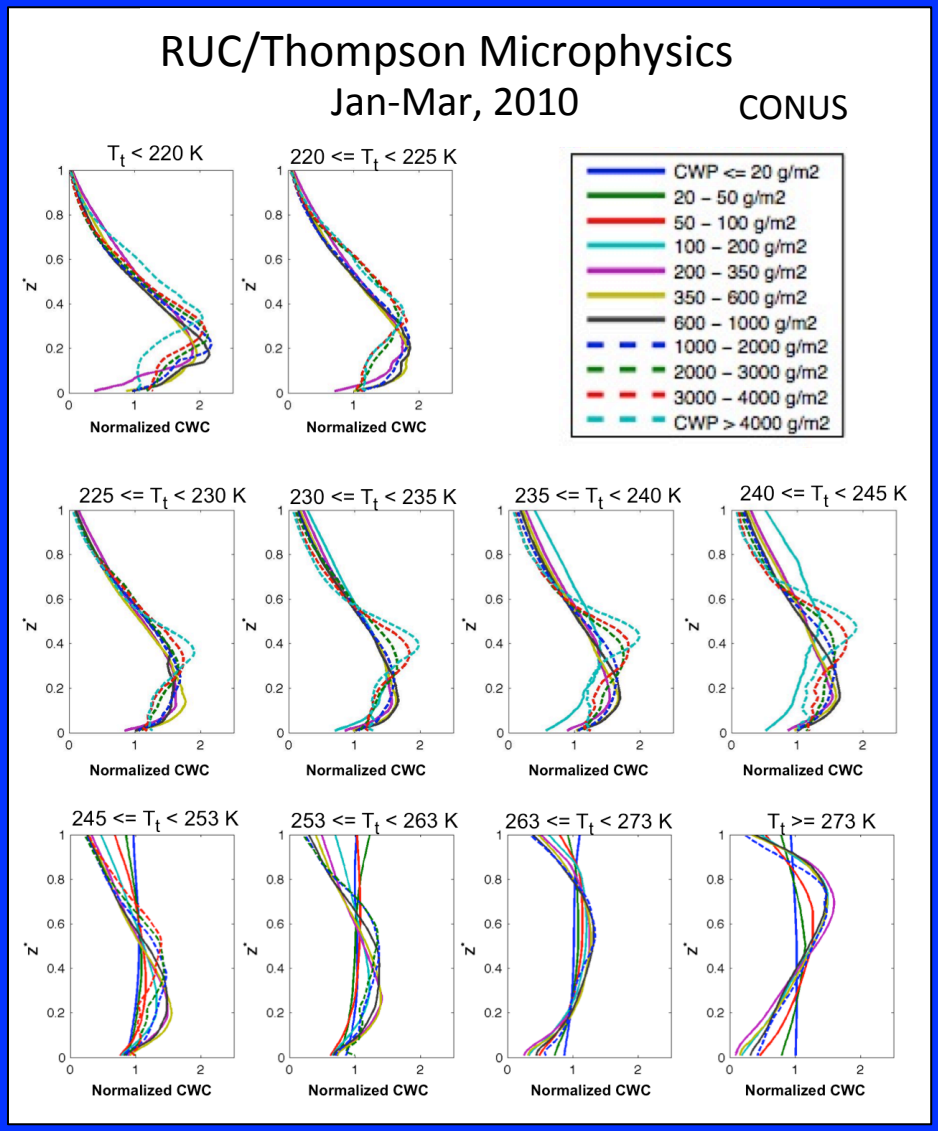
Parameterization for Total Water Path (TWP)



Typical Vertical Distribution of Total Water Content (TWC)

Combination of CloudSat + NWP yields best results





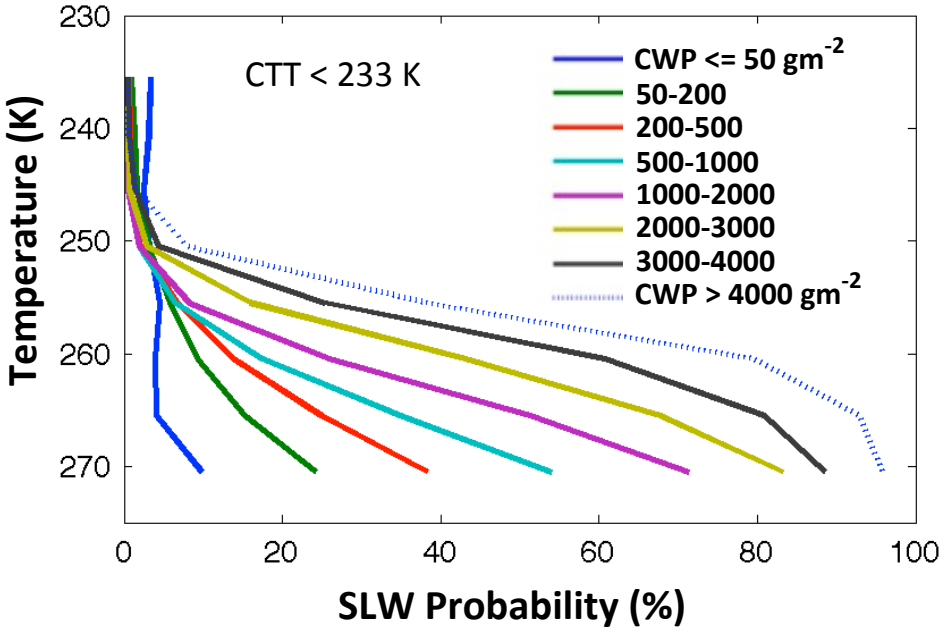
Cloud Phase Partitioning in Vertical

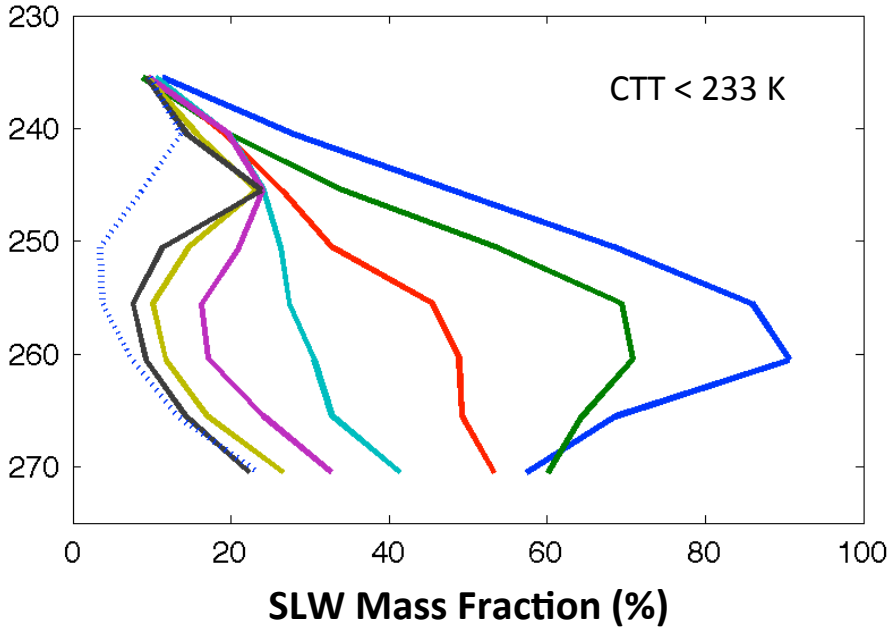
- Guidance from NWP cloud analyses
- Needed to derive IWC(z) and LWC(z) from TWC(z)
- Threshold on SLW probability is a function of satellite cloud properties (derived from correlations with icing PIREPS)

Thompson/NCAR Cloud Microphysics
liquid: $q_{liq} + q_{rain}$
ice: $q_{ice} + q_{snow} + q_{graupel}$

SLW probability and mass fraction

Climatological approach as a function of T for lots of cloud types (~50)

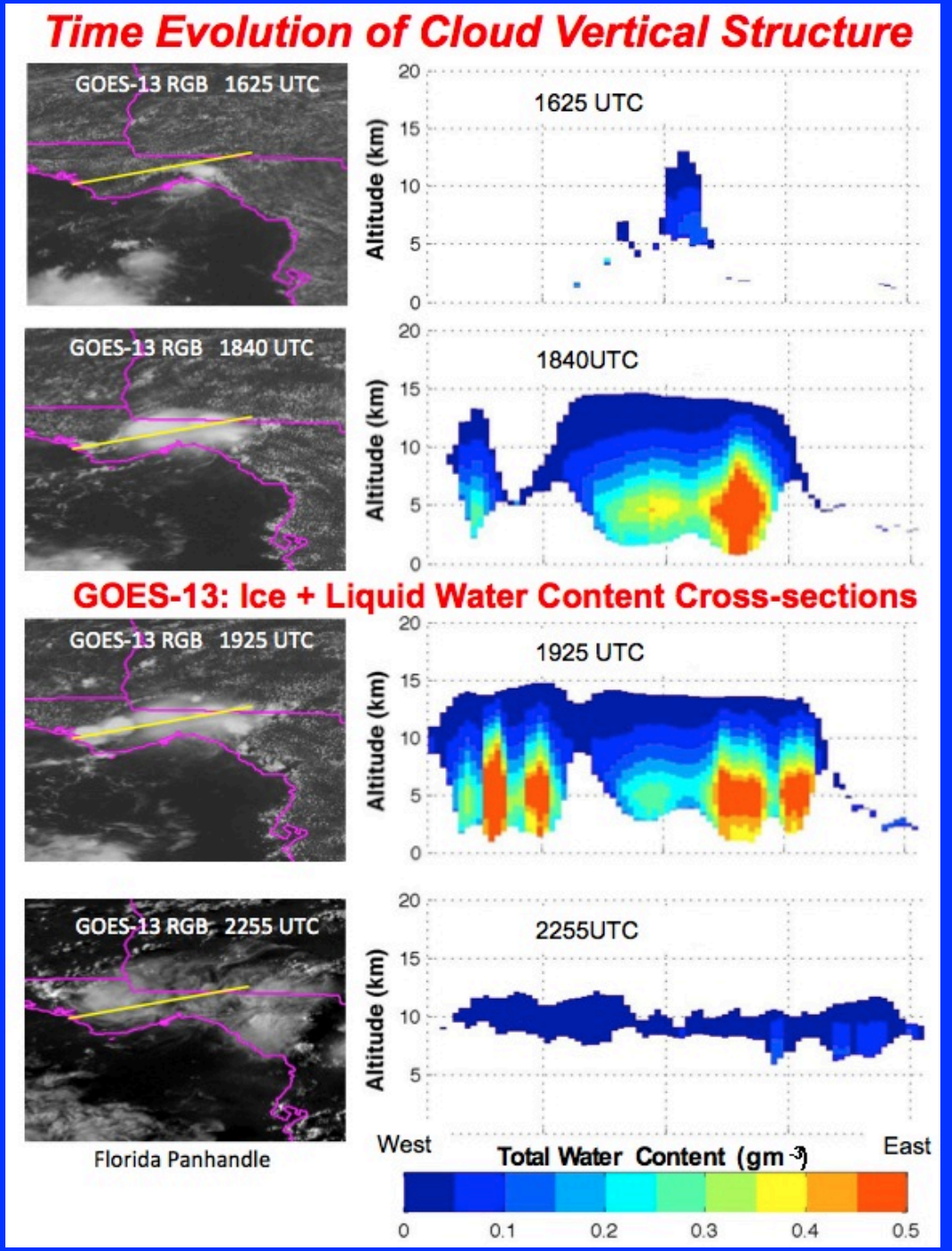




Jan-Mar, 2010

Profiling method has been applied to GOES and MODIS VISST cloud properties.

This example shows the time evolution of cloud ice and liquid water content derived from GOES for a short-lived thunderstorm outbreak over the Florida panhandle



Validation of IWC/IWP using C3M Data

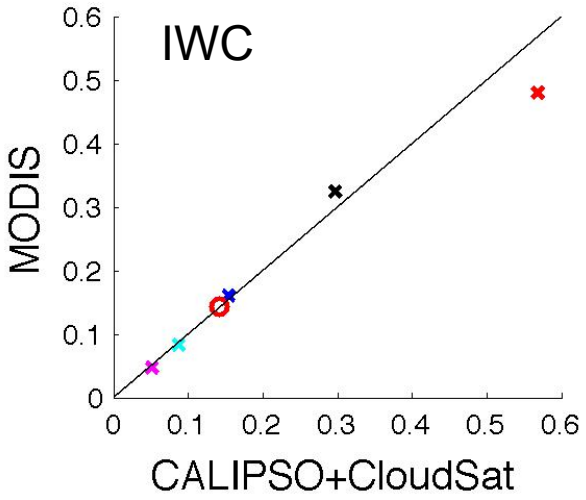
Profiling Method applied to MODIS Cloud Properties

April 2010 (CONUS), Optically thick clouds (ice phase tops, tau>10)

Monthly Means stratified by MODIS COD

IWC (g/m^3)

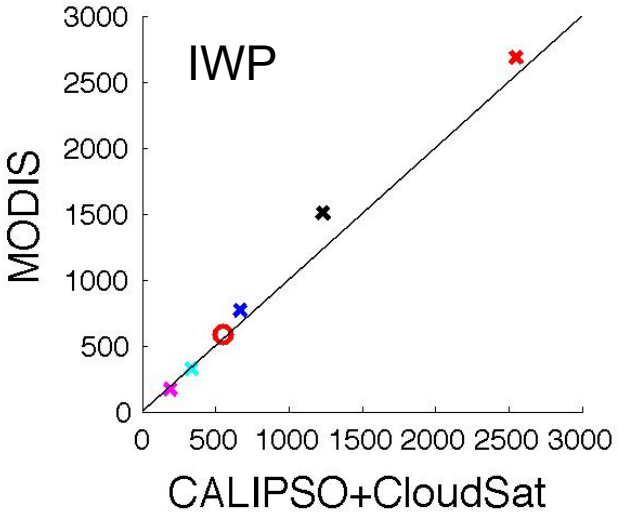
COD BIN	CALIPSO +CloudSat	MODIS	BIAS	N
10-20	0.051	0.047	-8%	5083
20-40	0.087	0.083	-5%	4149
40-80	0.154	0.161	5%	2635
80-150	0.297	0.325	9%	730
150	0.568	0.480	-15%	965
ALL	0.141	0.143	1%	13562



Assessed at altitudes above -20C level

IWP (g/m^2)

COD BIN	CALIPSO +CloudSat	MODIS	BIAS	N
10-20	191	169	-12%	5083
20-40	333	324	-3%	4149
40-80	668	767	15%	2635
80-150	1231	1507	22%	730
150	2549	2688	5%	965
ALL	551	583	6%	13562



Standard VISST IWP vs Profiling Method (full column)

Differences due to VISST vertical homogeneity assumptions:

1. Cloud phase assumption (embedded liquid interpreted as ice)
2. $R_e(z)$ = const

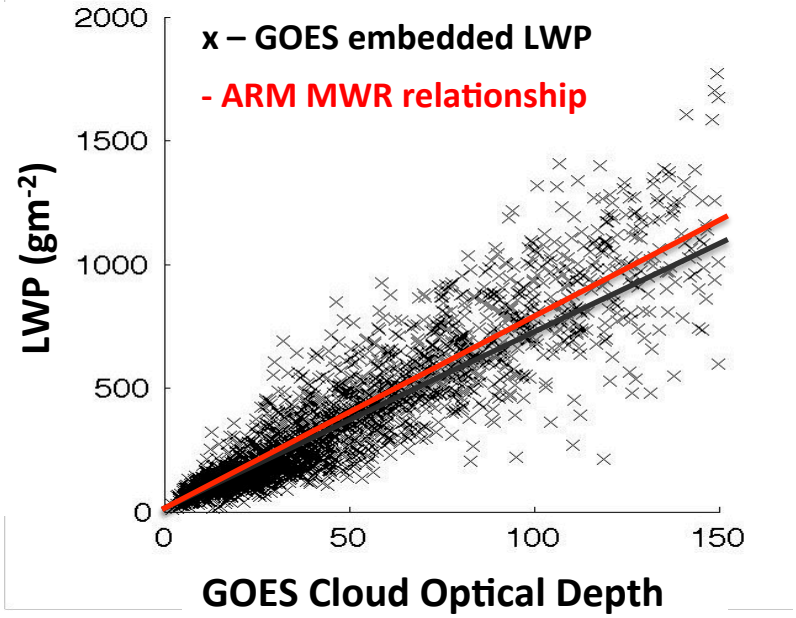
IWP (g/m^2)

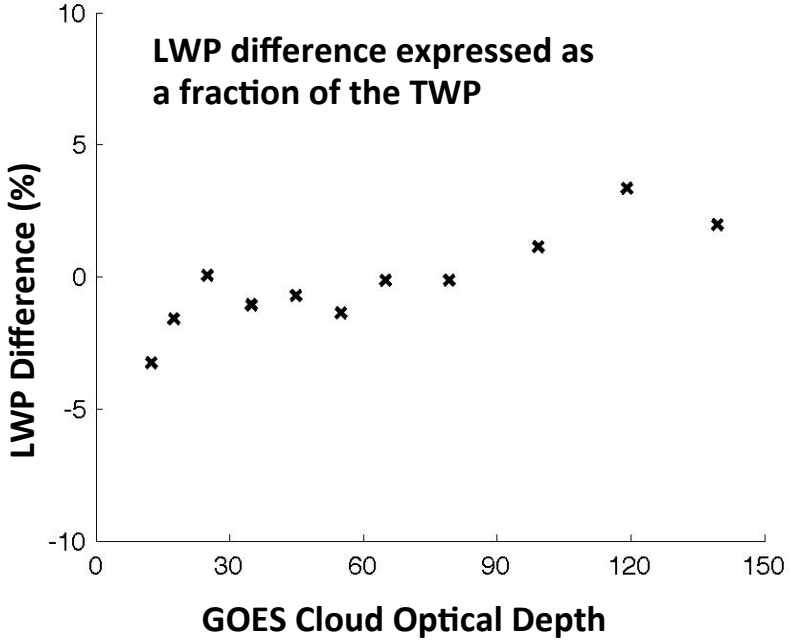
COD BIN	GOES VISST IWP	GOES Profile method IWP	GOES Profile method TWP	VISST BIAS (IWP) %	VISST BIAS (TWP) %	N
10-20	260	234	321	11%	-19%	62515
20-40	539	604	741	-11%	-27%	74047
40-80	1070	1368	1632	-22%	-34%	47192
80-150	2220	3228	3815	-38%	-42%	25905
150	2640	3960	4809	-33%	-45%	42893
ALL	1098	1494	1810	-27%	-39%	252552

- VISST overestimates IWP for optical depths between 10 and 20
  - error dominated by cloud phase assumption
- For higher optical depths, VISST underestimates IWP by 10-35 % (April 2010, CONUS)
  - errors increase with increasing COD (R_e assumption dominates)

LWP Validation

Single-layer ice over water clouds (known icing conditions)
CONUS, Jan-Mar, 2013





- **GOES retrieval matches MWR observations w.r.t retrieved COD**
- **Suggests NWP cloud phase partitioning is pretty good**

LWP Validation (Icing Conditions)

CONUS, Jan-Mar, 2013

Icing Detection

Satellite Method	N	PODY	Hit Rate
OVC Liquid Clouds	5759	99%	90%
OVC Ice Clouds	2713	98%	83%
All OVC Regions	11851	99%	88%

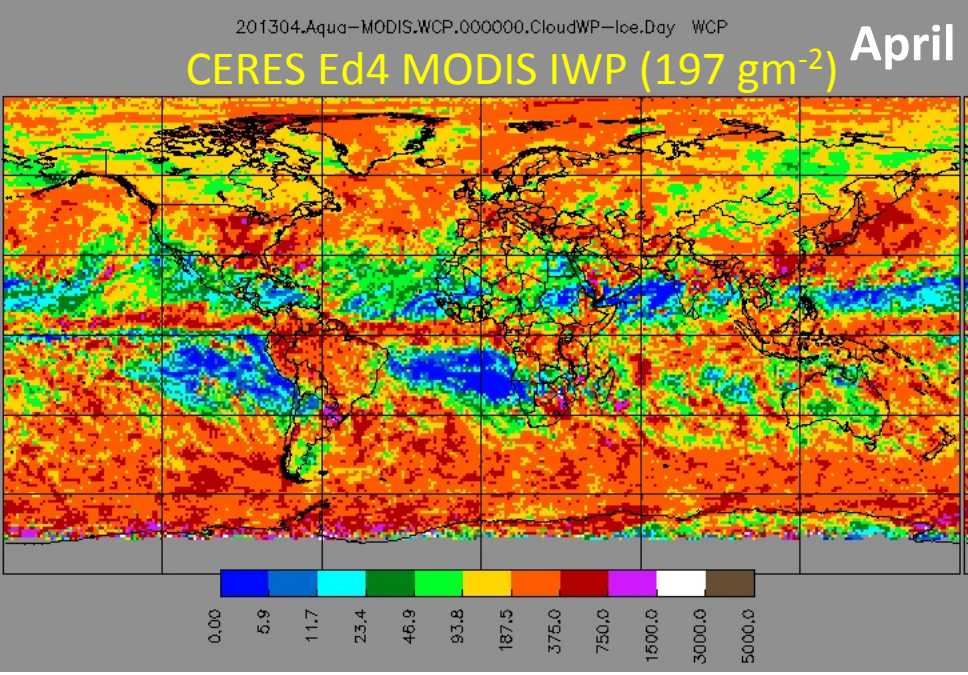
Icing detection beneath ice clouds is almost as accurate as that for unobscured low-level liquid clouds

Icing Intensity also has skill (separates light from MOG)

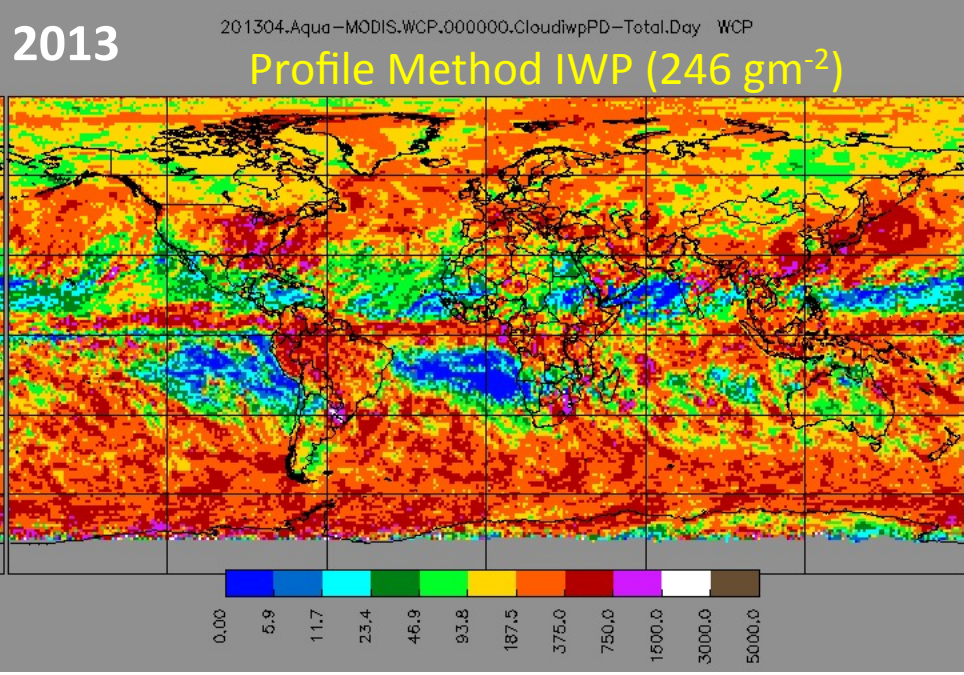
Source	N	PODL	PODM	Accuracy	Pirep %MOG	Sat
Liquid Clouds	5013	76%	66%	73%	27	36
Ice Clouds	2236	80%	47%	72%	26	27

Intensity accuracy similar for liquid and ice clouds.
Same fraction of intensities as observed

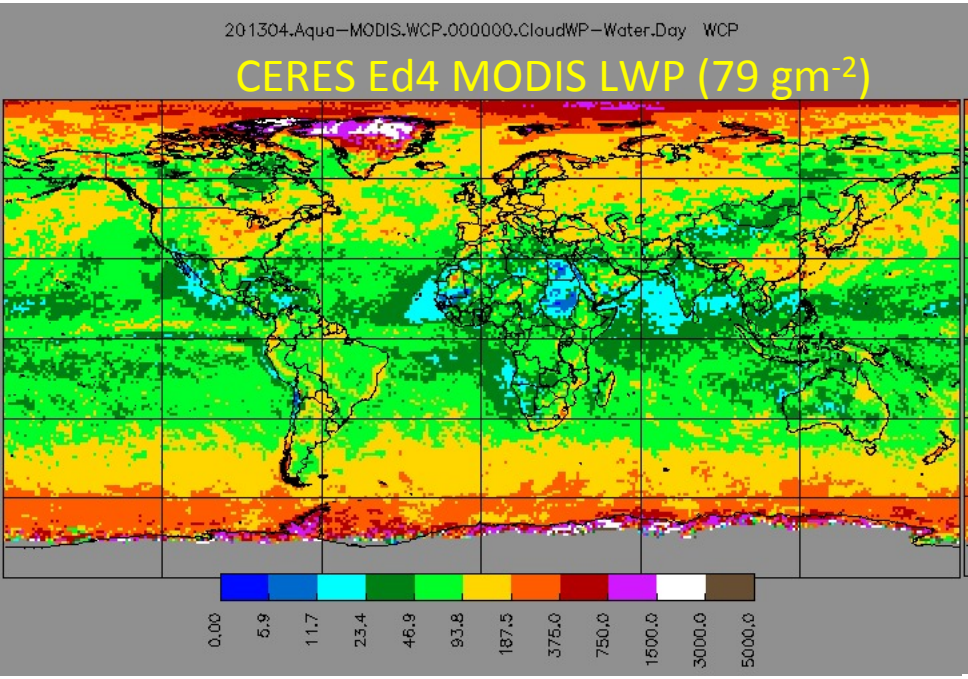
April 2013



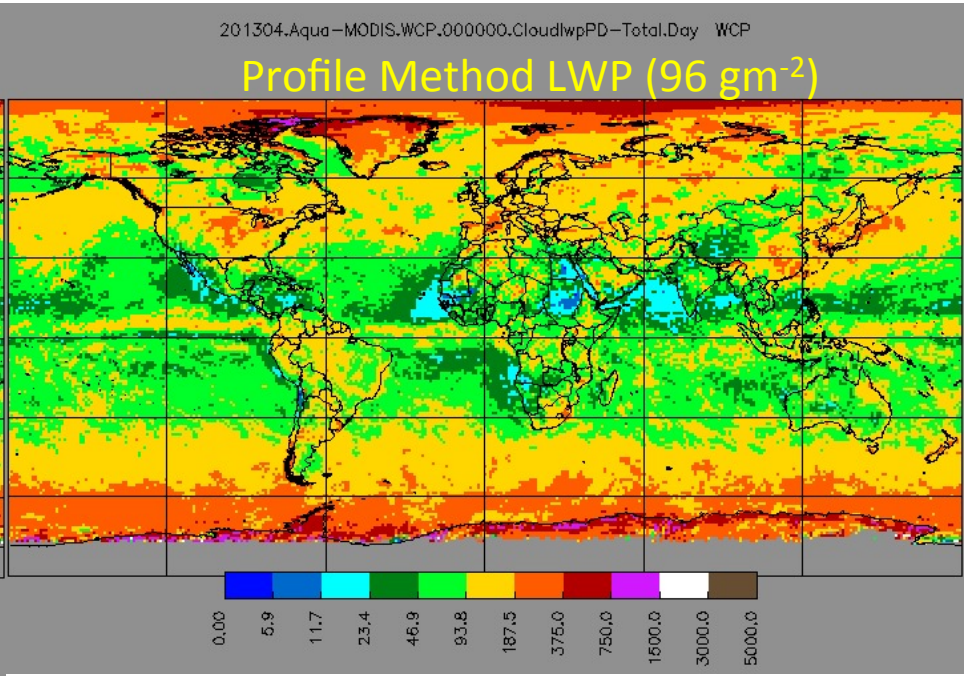
CERES Ed4 MODIS IWP (197 gm^{-2})



Profile Method IWP (246 gm^{-2})



CERES Ed4 MODIS LWP (79 gm^{-2})

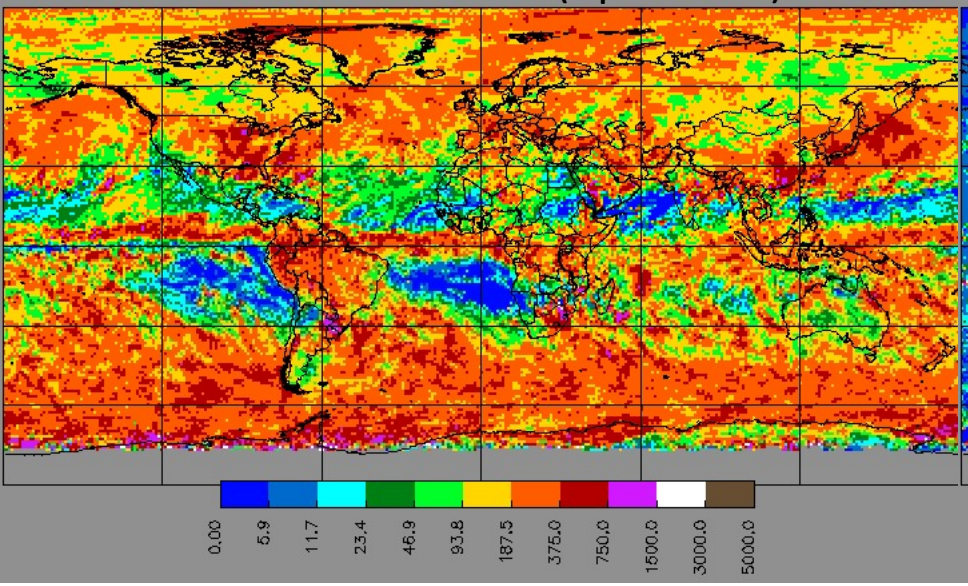


Profile Method LWP (96 gm^{-2})

Non-polar means (shown parentheses) increase ~25%

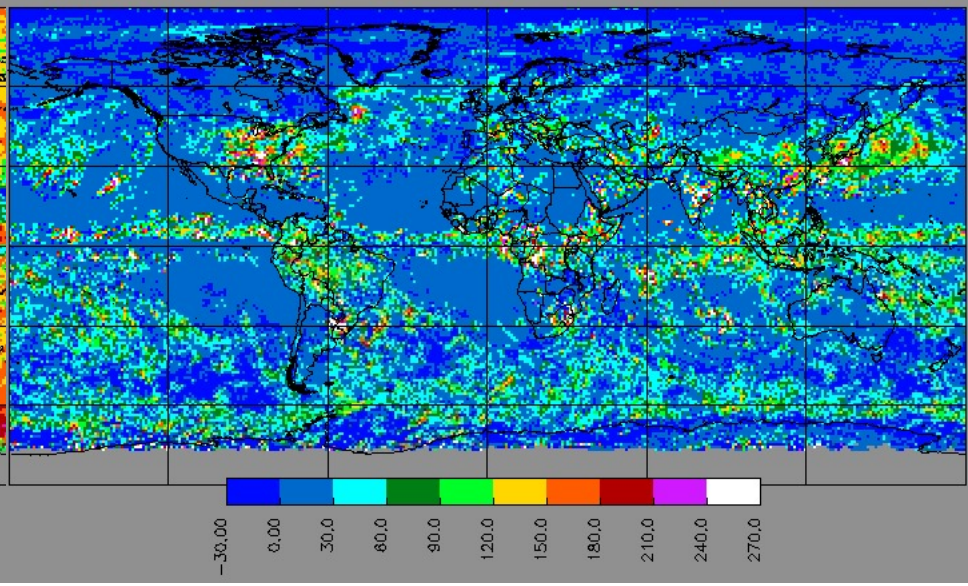
201304.Aqua-MODIS.WCP.000000.CloudWP-Ice.Day WCP

CERES Ed4 MODIS IWP (April 2013)



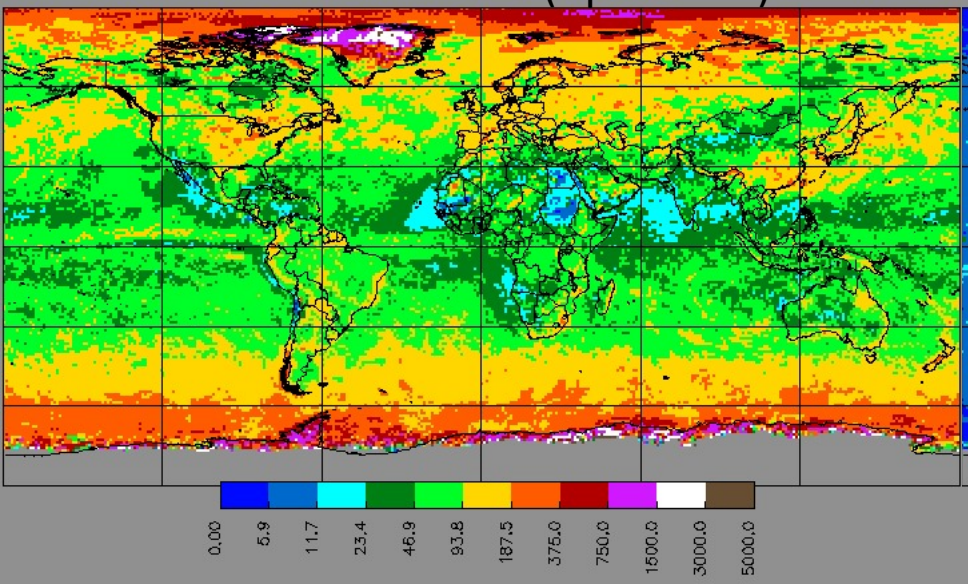
/201304.Aqua-MODIS.WCP.000000.CloudIwpPD-Total.minus.CloudWP-Ice.Day WCP

Profile method minus CERES IWP



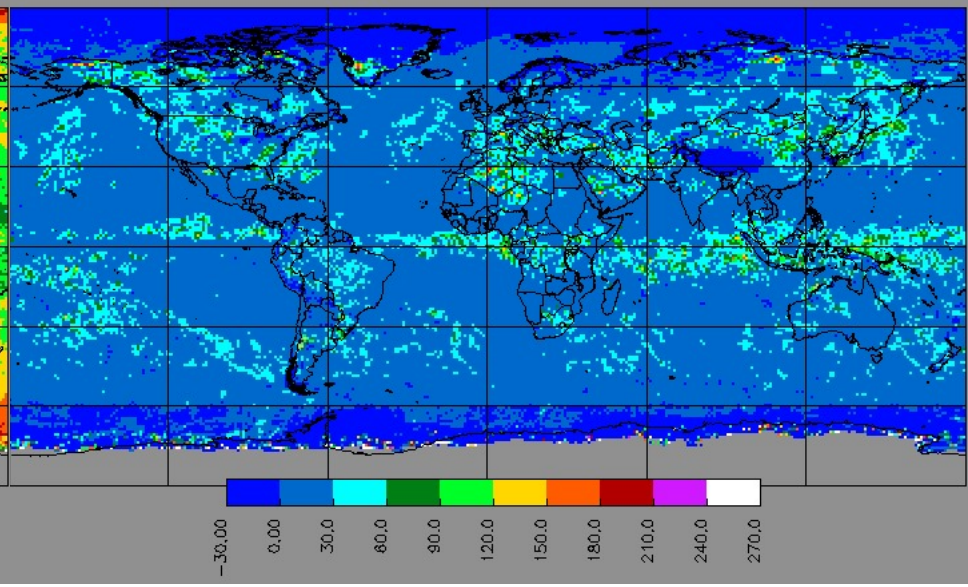
201304.Aqua-MODIS.WCP.000000.CloudWP-Water.Day WCP

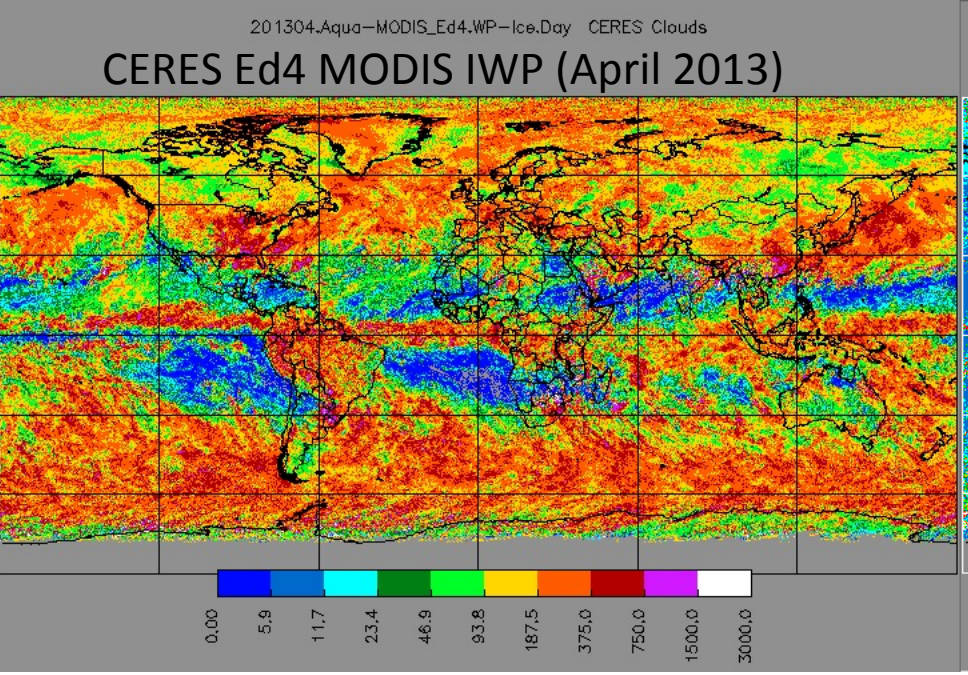
CERES Ed4 MODIS LWP (April 2013)



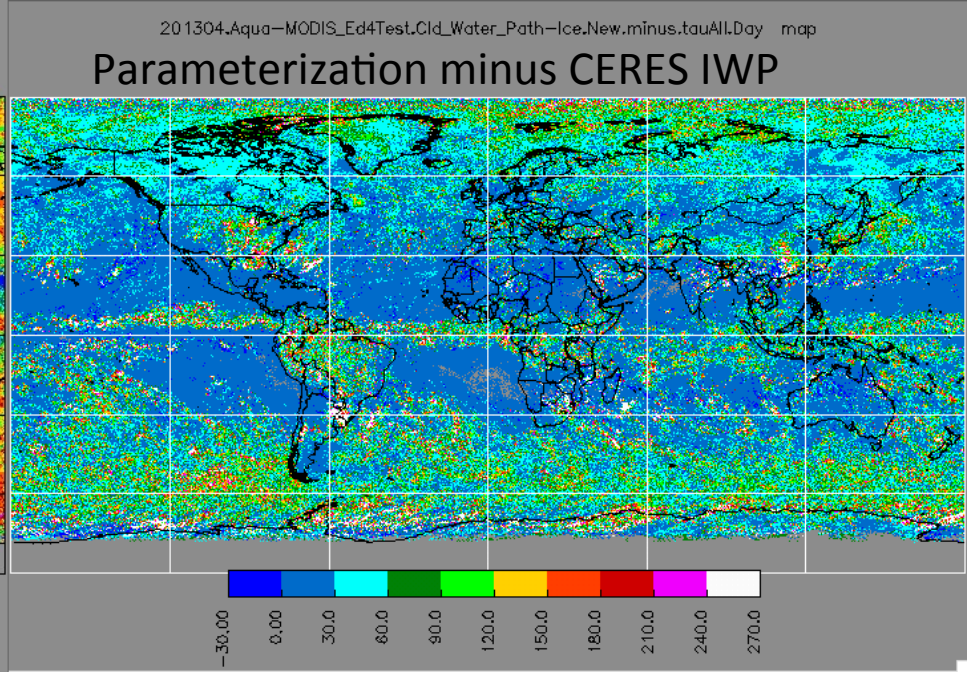
/201304.Aqua-MODIS.WCP.000000.CloudIwpPD-Total.minus.CloudWP-Water.Day WCP

Profile method minus CERES LWP

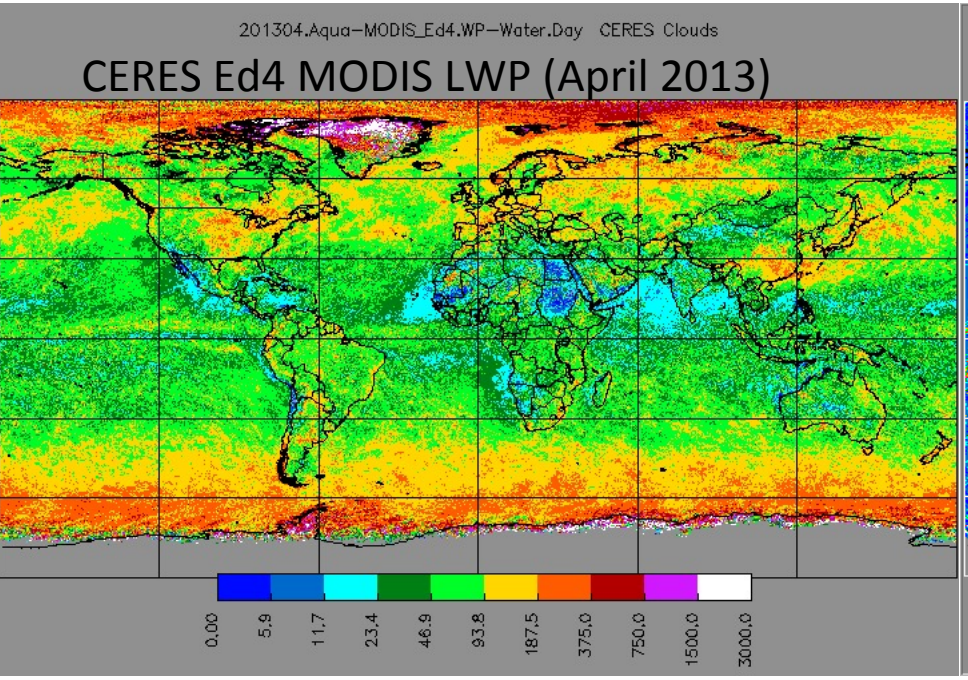




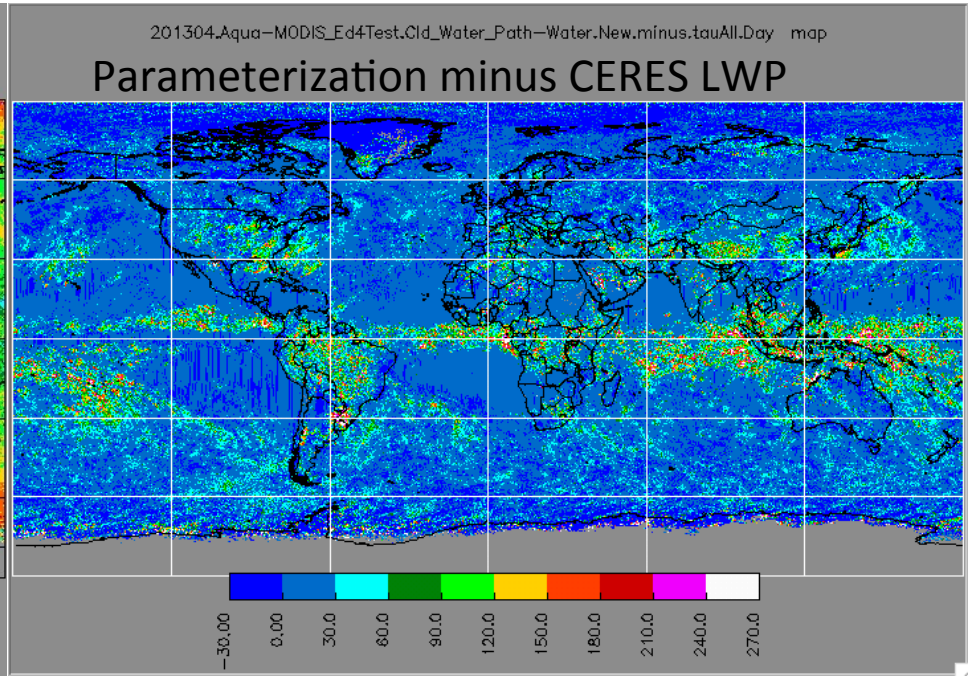
CERES Ed4 MODIS IWP (April 2013)



Parameterization minus CERES IWP



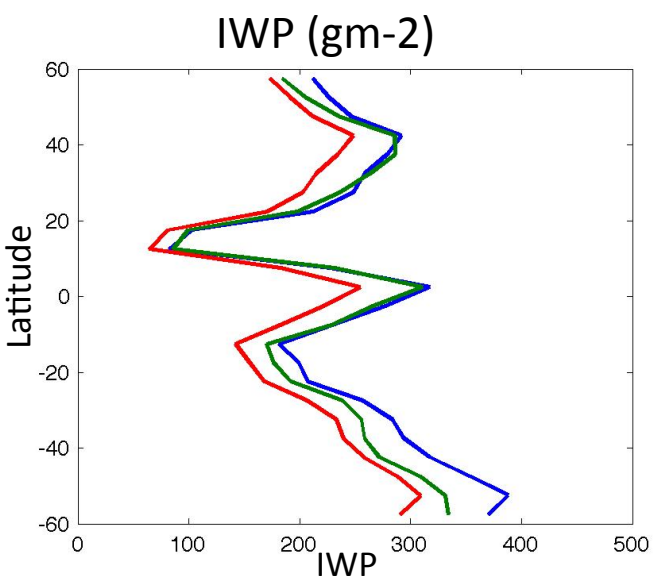
CERES Ed4 MODIS LWP (April 2013)

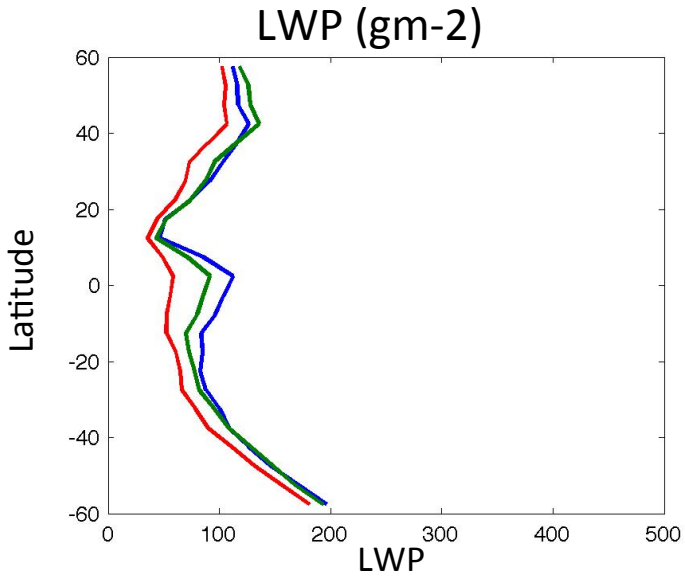


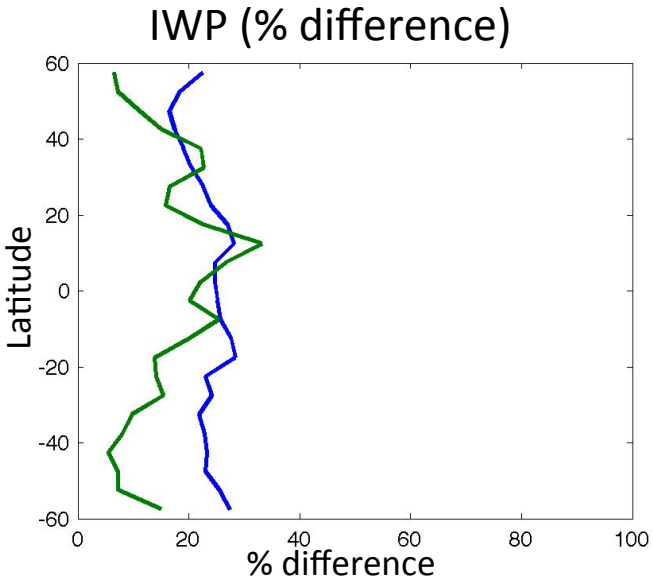
Parameterization minus CERES LWP

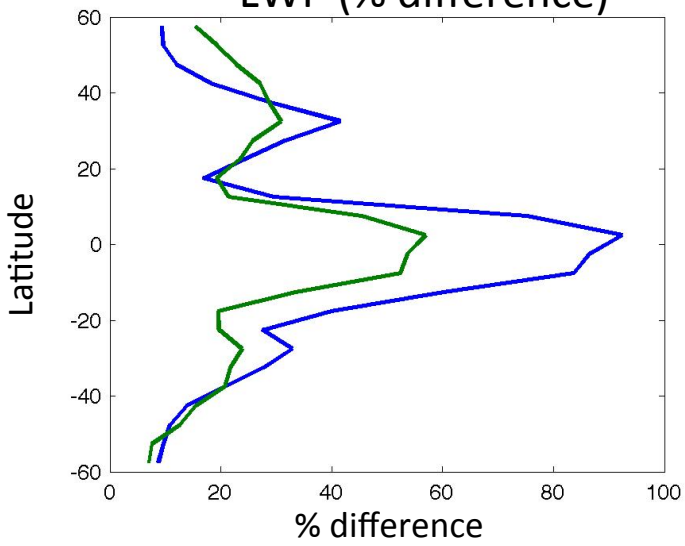
SL assumption causes errors (LWP underestimated in ML conditions?)

ZONAL MEANS


IWP (gm-2)
Latitude
IWP
60
40
20
0
-20
-40
-60
0
100
200
300
400
500


LWP (gm-2)
Latitude
LWP
60
40
20
0
-20
-40
-60
0
100
200
300
400
500


IWP (% difference)
Latitude
% difference
60
40
20
0
-20
-40
-60
0
20
40
60
80
100

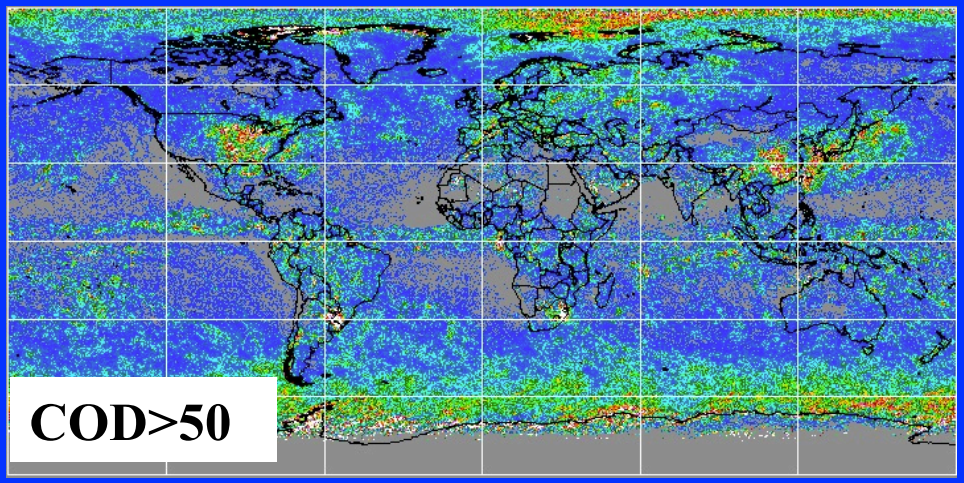

LWP (% difference)
Latitude
% difference
60
40
20
0
-20
-40
-60
0
20
40
60
80
100

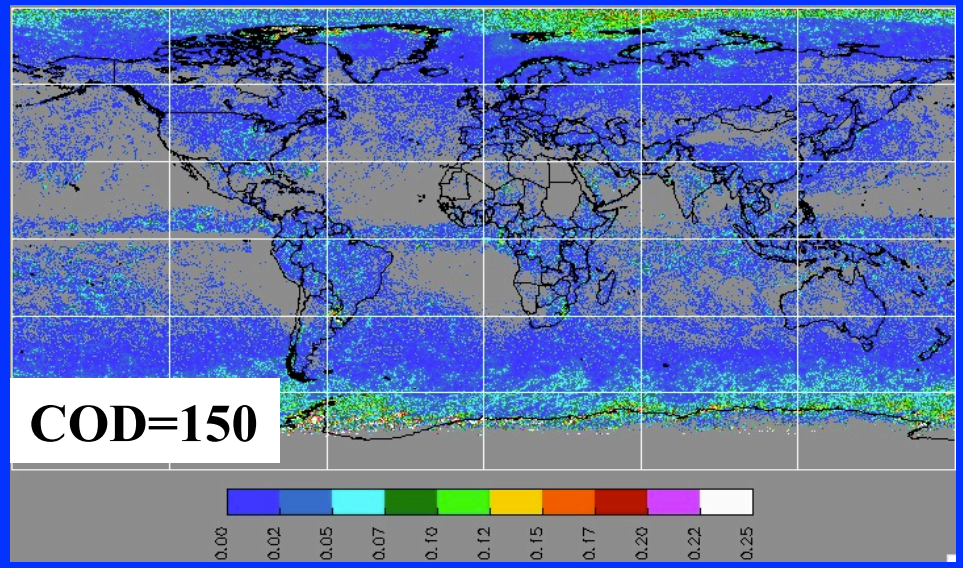
Summary

- Profiling technique is a passive sensor approach (don't need a cloud radar) fully constrained with imager cloud properties but incorporates best available information on cloud vertical structure from other sensors and models (albeit climatological)
- Can be applied anywhere that standard satellite imager cloud properties are available
- Provides high spatial and temporal resolution over wide areas, thus 3-D or 4-D cloud properties (from GEO)
- Validation for SL ice over water clouds suggests the method provides IWP and LWP estimates with unprecedented accuracy for a wide range of conditions
- Works over land and ocean
- Can be applied to all cloud types
- Much more work needed to improve the method for global application. SL assumption biggest source of error. Need to incorporate better information on ML clouds and cloud vertical structure (preferably obtained from the imager data).

BACKUPS

Ice Cloud Fraction





Relative contribution to mean IWP